МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри

_________Ларін В.Ю.

«__»____________ 2017р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

Тема: «Методика обчислення параметрів магнітного поля обмеженої території»

Виконавець: Миронюк О.О.

Керівник: Остроумов І.В.

Нормоконтролер: Ларін В.Ю.

Київ 2017

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Навчально-Науковий Інститут Аеронавігації

Кафедра Аеронавігаційних Систем

Спеціальність: 8.07010203 « Системи аеронавігаційного обслуговування»

ЗАТВЕРДЖУЮ

Завідувач кафедри

_____________Ларін В.Ю.

«__»______________2017р.

ЗАВДАННЯ

на виконання дипломної роботи

Миронюк Олени Олександрівни

1. Тема дипломної роботи «Методика обчислення параметрів магнітного поля обмеженої території» затверджена наказом ректора від 11 жовтня 2016р. № 2600/ст.

2. Термін виконання роботи: з 11.10.2016 по 20.01.2017.

3. Вихідні дані до роботи: документи Міжнародної організації моніторингу стану магнітного поля землі, NASA і технічна інформація .

4. Зміст пояснювальної записки: основи магнітного поля Землі, опис датчиків кишенькового пристрою, вимірювання та обробка даних магнітного поля локально.

5. Перелік обов'язкового графічного (ілюстративного) матеріалу: графіки результатів даних, таблиці, формули.

6. Календарний план-графік

№ п/п	Завдання	Термін Виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Основи магнітного поля»	11.10.16-26.10.16	виконано
2.	Підготовка та написання 2 розділу «Датчики кишенькового пристрою»	27.10.16-11.11.16	виконано
3.	Підготовка та написання 3 розділу «Обробка даних вимірювань магнітного поля Землі локально»	12.11.16-01.12.16	виконано
4.	Підготовка та написання 4 розділу «Експериментальне вимірювання магнітного поля Землі локально»	02.12.12-02.01.17	виконано
5.	Підготовка презентації та доповіді	03.01.17-20.01.17	виконано

7. Дата видачі завдання: « 11 » жовтня 2016 р.

Керівник дипломної роботи ____________________ Остроумов Іван Вікторович
(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання _____________ Миронюк Олена Олександрівна
(підпис студента) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Методика обчислення параметрів магнітного поля обмеженої території»: 104 сторінок, 54 рисунків,1 таблиця ,40 використаних джерел,2 додатка.

Об'єкт розробки – інтегрована система вимірювання параметрів магнітного поля.

Предмет розробки – оцінювання характеристик магнітного поля за даними сенсорів кишенькового пристрою.

Мета роботи – розробка методики оцінювання параметрів магнітного поля для обмеженої території за даними вимірювань кишенькового пристрою.

Метод дослідження – комп'ютерне моделювання та експерементальне випробування.

Магнітне поле Землі є одним з найважливіших речей планетарної структури. Також магнітне поле є одним з ключових елементів для цілей навігації. Його параметри надзвичайно важливі для виявлення напрямку, навігації та функціонування інших програм. Сучасні навігаційні прилади та датчики, засновані на характеристиках магнітного поля, використовують моделі магнітного поля, які не містять дані про людський фактор магнітного поля.

Всі датчики, які нам потрібні, ми можемо знайти всередині типового планшету або в сучасного мобільного телефону. Тому, потрібно три магнітометри, три гіроскопи (для виявлення кутового положення планшета) і датчик позиціонування – GNSS-приймач (у складі даних). Нажаль різні датчики всередині мобільного телефону мають різний час вимірювань. Щоб вирішити цю проблему, потрібно інтерполювати координати для того, щоб об'єднати датчики часу. Результати роботи відзначають, що датчики мобільного телефону можна використовувати в режимі реального часу оцінки характеристик магнітного поля.

МАГНІТНЕ ПОЛЕ, МОБІЛЬНИЙ ТЕЛЕФОН, ІНТЕРПОЛЯЦІЯ, ПОЛІНОМ,МАГНІТОМЕТРИ, АПРОКСИМАЦІЯ,DATA RECORDING, ДАТЧИКИ.

NOTES

MINISTRY OF EDUCATION AND SCIENCE, OF UKRAINE
NATIONAL AVIATION UNIVERSITY

Air Navigation System Department

PERMISSION TO DEFEND
GRANTED
Head of the Department
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«__»__________________2017

MASTER'S DEGREE THESIS

Theme: « Method of parameters calculation of magnetic field of restricted area»

Completed by: Mironyuk O.O.
Supervisor: Ostroumov I.V.
Standarts Inspector: Larin V.Yu.

Kyiv 2017

NATIONAL AVIATION UNIVERSITY

Educational and Scientific Institute of Air Navigation
Air Navigation Systems Department
Specialty: 8.07010203 « Systems of Aeronavigation Service »

APPROVED BY
Head of the Department
_____________ V.Yu. Larin
«__»___________________2017

Graduate Student's Degree Thesis Assignment

Mironyuk Olena

1. The Project topic: «Method of parameters calculation of magnetic field of restricted area » approved by the Rector's order of « 11 » October 2016 № 2600/st.
2. The Project to be completed between: 11.10.2016 – 20.01.2017.
3. Initial data to the project: documents of the international organizations monitoring the state of Earth's magnetic field, NASA and technical information.
4. The content of the explanatory note (the list of problems to be considered): basics of magnetic field,sensors of smartphone, local magnetic field data processing,sensing of local magnetic field.
5. The list of mandatory graphic (illustrated) materials: graphs of results data, tables, formulas.

6. Calendar timetable

№	Completion stages of Degree Project	Stage completion dates	Remarks
1	Preparation of chapter 1: « Basics of magnetic field »	11.10.16-26.10.16	completed
2	Preparation of chapter 2: « Sensors of smartphone »	27.10.16-11.11.16	completed
3	Preparation of chapter 3:« Local magnetic field data processing »	12.11.16-01.12.16	completed
4	Preparation of chapter 4: « Sensing of local magnetic field »	02.12.12-02.01.17	completed
5	Preparation of report and graphic materials	03.01.17-20.01.17	completed

7. Assignment accepted for completion «11» October 2016

Supervisor____I.V.Ostroumov

Assignment accepted for completion __________________________O.O. Mironyuk

ABSTRACT

Explanatory note to the master's thesis, « Method of parameters calculation of magnetic field of restricted area »: 104 pages, 54 figures, 1 tables ,40 references, 2 appendixes.

Development object – integrated system for measuring parameters of magnetic field.

Development subject – estimation of characteristics of the magnetic field sensor according pocket devices.

Purpose of the work – the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Investigation method – computer modeling and experimental testing.

Global Earth's Magnetic field is one of the most important things in planetary structure. Magnetic field is also one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications.

Modern navigation devices and sensors grounded on magnetic field characteristics use magnetic field models which do not contain data about human based part of magnetic field.

All sensors which we need can be found inside of typical tablet or in modern cell phone . That's way it is need 3 magnetometers, 3 gyroses (to detect angular position of tablet) and positioning sensor – GPS receiver (to data composition)

Unfortunately different sensors inside mobile phone have different time of measurements. To make this time problem clear it is necessary to interpolate coordinates in order to unify sensors data time.Results of work indicate that mobile phone sensors can be used for real time magnetic field characteristics estimation.

MAGNETIC FIELD, MOBILE PHONE INTERPOLATION, POLYNOMIAL, MAGNETOMETERS, APPROXIMATION,DATA RECORDING, SENSORS.

CONTENT

LIST OF ABBREVIATION

ASM – Absolute Scalar Magnetometer

CG – Center of Gravity

CME – Coronal Mass Ejections

CMG – Control Moment Gyroscope

CNES – National Center for Space Studies

CSC – Compact Spherical Coil

ECEF – Earth-Centered Earth-Fixed Coordinate System

ENU – East-North-Up

ESA– European Space Agency

GPS – Global Positioning System

IAGA – International Association of Geomagnetism and Aeronomy

IGRF– International Geomagnetic Reference Field

IMF – Interplanetary Magnetic Field

NASA – National Aeronautics and Space Administration

NMR – Nuclear Magnetic Resonance

NOAA – National oceanic and atmospheric administration

OVH – Overhauser magnetometer

PWM – Pulse-Width Modulation

SV – Secular Variation

TSV – Tab-Separated Values

UPS – Universal Polar Stereographic

USGS – U.S. Geological Survey

UTM – Universal Transverse Mercator

VFM – Vector Field Magnetometer

WMM – World Magnetic Model

INTRODUCTION

Thesis actuality. Global Earth's Magnetic field is one of the most important things in planetary structure. Also magnetic field is one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications. For example in inertial navigation systems global magnetic field has been used for sensors calibration. Characteristics of magnetic field have been using for rotation detection and angular speed calculation too. Typically total magnetic field in some point of atmosphere has been sum of thee different components: main magnetic field – is result of geomagnetic process inside of Earth core; external magnetic field – is result of sun influence, depends on current solar activity and usually less than 5% of total magnetic field; anomalous – is result of influence of different ground anomalous areas which contain some ore deposits with magnetic characteristics in earth crust. Nowadays it is possible to detect influence of different human – made structures to total magnetic field. This is the result of wide metal construction usage in city building. Of course this type of influence is a part of anomalous magnetic field, but it is directly connected with results of human changing. In this case we can access natural and human based components of anomalous field. Also for humane based part we can include different electrical devices which can result in magnetic injection.

Nowadays different international programs investigate and monitor characteristics of magnetic field. National oceanic and atmospheric administration (NOAA), U.S. Geological Survey (USGS), Swarm earth explorers by European Space Agency (ESA) investigate this problem, but in common way all of them are been oriented into global scale of magnetic field.

Modern navigation devices and sensors grounded on magnetic field characteristics have been using magnetic field models which don't contain data about humane-based part of magnetic field. In result non accurate model produce errors which will be in result of positioning or heading error. In some cases influence of human-based field will be very valuable for navigation purposes. That's why the aim of this work to describe methodology of local magnetic field parameters measurement by typical users equipment.

Thesis relation with scientific research programs, schedules and themes

Scientific research was done in the framework of international fundamental researches of the international organizations monitoring the state of Earth's magnetic field and NASA.

Investigation object - integrated system for measuring parameters of magnetic field.

Investigation subject - estimation of characteristics of the magnetic field sensor according pocket devices.

Purpose of the work - the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Investigation method - computer modeling and experimental testing.

Science research novelty - results of work indicate that mobile phone sensors can be used for real time magnetic field characteristics estimation.

Practical results of science research. The results of scientific’s work will be published in Proceeding of the NAU issue 1 in 2015, represented in the scientific conferences and the program will receive a patent.

This new program for the construction of software for inertial positioning systems and navigation systems.

CHAPTER 4. LOCAL MAGNETIC FIELD DATA PROCESSING

4.1. Method of magnetic field data processing

There are several sensors in the smartphone. Such as GNSS, gyroscopes, magnetic field sensors and accelerometers.

With the help of GPS receiver we measured: Height – a scalar value, in meters; Lat – scalar geodetic latitude, in degrees, where north latitude is positive and south latitude is negative; Lon – A scalar geodetic longitude, in degrees, where east longitude is positive, and west longitude is negative.

With the help of Magnetic Field sensors – Tx, Ty, Tz – components of magnetic field vector in nanotesla (nT), usually. With the help of Gyroscope– rotation angle data.

These data are recorded in the special program «Data Recording». They are saved and available for processing in Matlab. Then we interpolate to a unique time.

We transform the coordinates to the NED-coordinate system.Next we calculate inclination,diclination,H and V (components of magnetic field vector).

Then we predictparameters of magnetic field for these coordinates and unique time[1].

Data interpolation in 3D space are for real and interpolate data.In the next we calculate difference between the obtained results and achieve the results visualization (Fig.4.1).

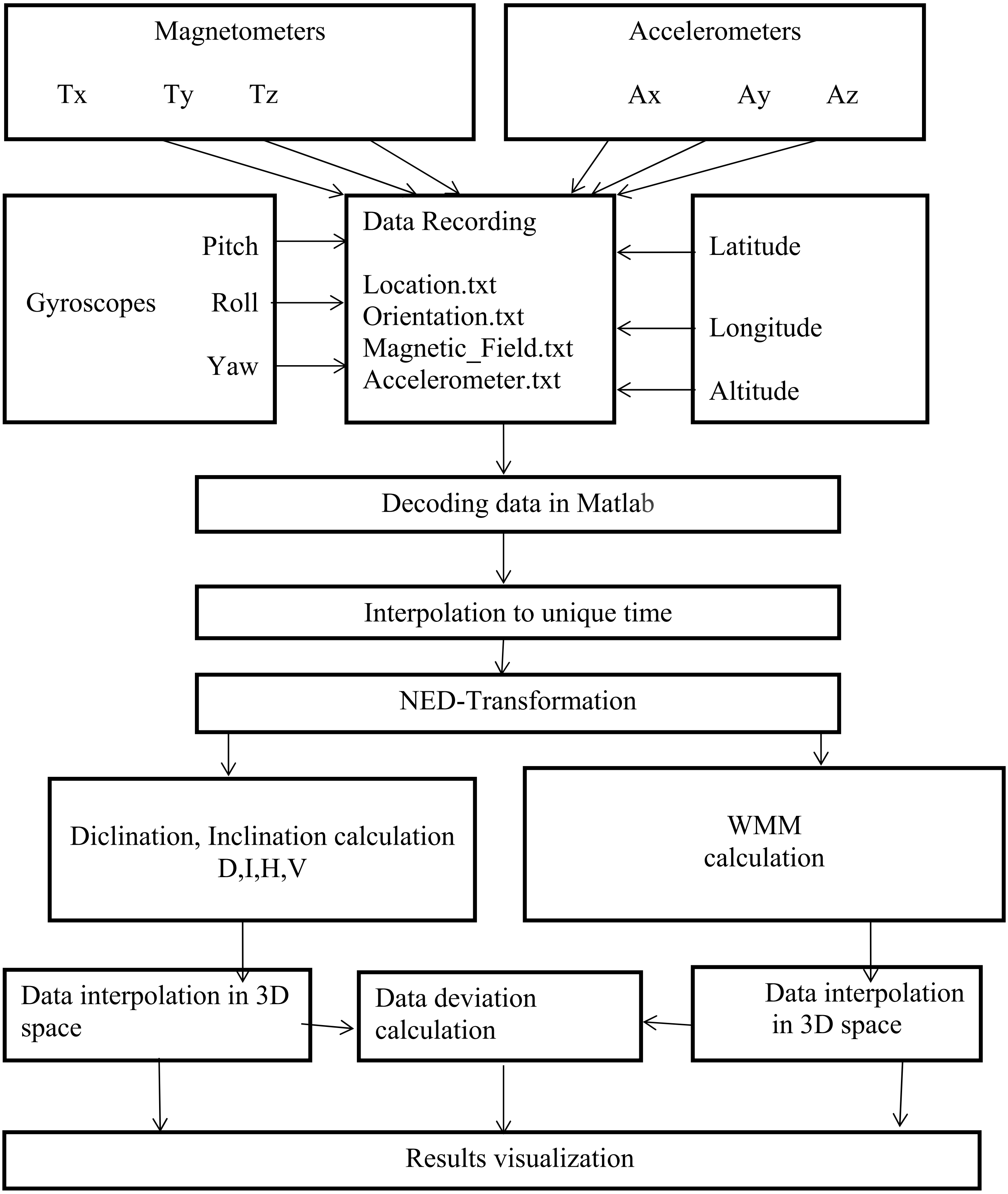

Figure 4.1 – Structure scheme method of magnetic paratemers calculation

4.2. Data transformation for the same time

Unfortunately different sensors inside of mobile phone have different time of measurements [4]. It means that each sensor measures in some specific time scale. For example in experiment GPS module provides us 1 result per second and other sensors 10 times per second. To make clear this time problem it is necessary to interpolate coordinates to unify sensors data time. The easiest way to do it is the usage of polynomial approximation. Let's use polynomial interpolation with m^{th} order of the polynomial:

$$y = A_0 + A_1 x + A_2 x^2 + A_3 x^3 + \ldots + A_m x^m , \tag{4.1}$$

where A_i are polynomial coefficients with i=0…m.

By result of measurement polynomial coefficients will be calculated.

In this case the least square method will be used for calculation. But at first let's compose system of math equation which helps to calculate polynomial coefficients:

$$\begin{cases} A_0 S_0 + A_1 S_1 + A_2 S_2 + \ldots + A_m S_m = B_0 \\ A_0 S_1 + A_1 S_2 + A_2 S_3 + \ldots + A_m S_{m+1} = B_1 \\ A_0 S_2 + A_1 S_3 + A_2 S_4 + \ldots + A_m S_{m+2} = B_2 \\ \ldots \\ A_0 S_m + A_1 S_{m+1} + A_2 S_{m+2} + \ldots + A_m S_{2m} = B_m \end{cases} , \tag{4.2}$$

where $S_k = \sum_{i=1}^{n} x_i^k$, $k = 1 \ldots m$,

$S_0 = n + 1$, n-number of measurements,

$B_k = \sum_{i=1}^{n} (y_i \cdot x_i^k)$.

Let's represent it in matrix form:

$$A \times S = B , \tag{4.3}$$

where

$$A = \left| A_0 , A_1 , \ldots A_m \right| , \tag{4.4}$$

$$S = \begin{vmatrix} S_0 \ S_1 \ S_2 \ldots S_m \\ S_1 \ S_2 \ S_3 \ldots S_{m+1} \\ S_2 \ S_3 \ S_4 \ldots S_{m+2} \\ \ldots \\ S_m \ S_{m+1} \ S_{m+2} \ldots S_{2m} \end{vmatrix} , \quad B = \begin{vmatrix} B_0 \\ B_1 \\ B_2 \\ \ldots \\ B_m \end{vmatrix} \tag{4.5}$$

Then, polynomial coefficients will be calculated by the next formula

$$A = B \times inv(S)\,. \tag{4.6}$$

These coefficients will be inserted into the main formula of the polynomial to calculate position for required time. Result of interpolation for different coordinates has been represented on figure 3 and 4 for time closed to 1500 second.

To increase computation time it is possible to use polynomial with less order, but in this case interpolation errors increase rapidly.

4.3. Coordinate systems

4.3.1. ECEF

The ECEF (Earth-Centered Earth-Fixed Coordinate System) coordinate system rotates with the earth around its spin axis. As such,a fixed point on the earth surface has a fixed set of coordinates. The origin and axes of the ECEF coordinate system (see Fig.4.2) are defined as follows:

1. The origin (denoted by Oe) is located at the center of the earth.
2. The Z-axis (denoted by Ze) is along the spin axis of the earth, pointing to the north pole.
3. The X-axis (denoted by Xe) intersects the sphere of the earth at 0° latitude and 0° longitude.
4. The Y-axis (denoted by Ye) is orthogonal to the Z- and X-axes with the usual right-hand rule. Coordinate vectors expressed in the ECEF frame are denoted with a subscript e.

Similar to the geodetic system, the position vector in the ECEF frame is denoted by

$$P_e = \begin{pmatrix} x_e \\ y_e \\ z_e \end{pmatrix} \tag{4.7}$$

CHAPTER 5. SENSING OF LOCAL MAGNETIC FIELD

5.1. Description of experiment

Magnetic field is characterized by intensity vector, usually. Intensity vector "*T*" is the sum of the vectors strengths of several fields [1]. Typically, the vector *T* is estimated from its projections, on the some Cartesian coordinate system (T_x, T_y, T_z components). Also two angles are important: declination (*D*) and inclination (*I*), which indicate position of intensity vector in space, horizontal T_H and vertical Tz components of *T*.

Declination is positive for an eastward deviation of the field relative to true north. It can be estimated by comparing the magnetic north/south heading on a compass with the direction of a celestial pole.

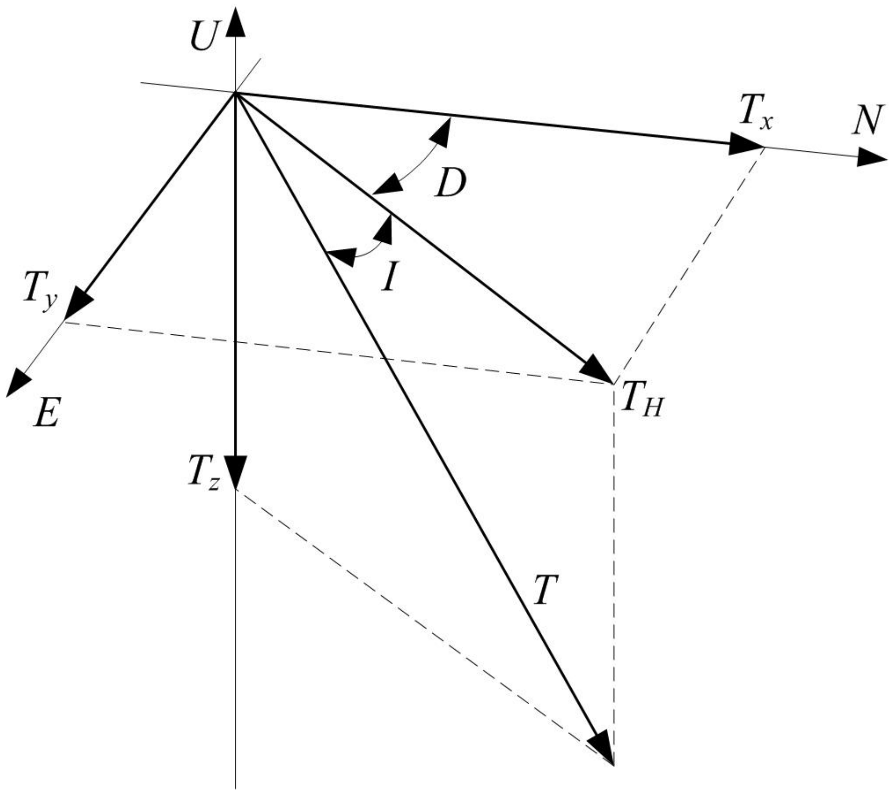

Figure 5.1 – Components of magnetic field intensity vector

The inclination is given by an angle that can assume values between -90° (up) to 90° (down). In the northern hemisphere, the field points downwards. It is straight down at the North Magnetic Pole and rotates upwards as the latitude decreases until it is horizontal (0°) at the magnetic equator.

All sensors which we need can be found inside of typical tablet or in modern cell phone [3]. That's way it is need 3 magnetometers (they will sense *Tx, Ty, Tz* components of intensity vector), 3 gyroses (to detect angular position of tablet) and positioning sensor – GPS receiver (to data composition).

With the help of GPS receiver we measured: Height - a scalar value, in meters; Lat - scalar geodetic latitude, in degrees, where north latitude is positive and south latitude is negative; Lon - A scalar geodetic longitude, in degrees, where east longitude is positive, and west longitude is negative. With the help of Magnetic Field sensors – *Tx, Ty, Tz* – components of magnetic field vector in nanotesla (nT), usually. With the help of Gyroscope – rotation angle data.

During an experiment cell phone Samsung Galaxy I9300 was used, and free Android application "Data Recording" for data collecting and storing.

As a result of software measurement we obtained t ext files with measured data. Pitch, roll and azimuth - these variables determine the position of device in the space. Azimuth serves as a compass, returning a value from 0 to 360 degrees, where 0 is north. Roll, which defines the "looks" screen phone in the ground or in the sky returns a value from 0 to 180 degrees, as you turn the phone to the right (180 degrees when the screen looks down), and from 0 to -180 as you turn your phone left. Pitch determines the angle of the phone in an upright position, returns a value from 0 to 180 (when tilted to the right) and from 0 to -180 when tilted to the left[3].

Trajectory of measurement and result of positioning is represented on fig.5.2.

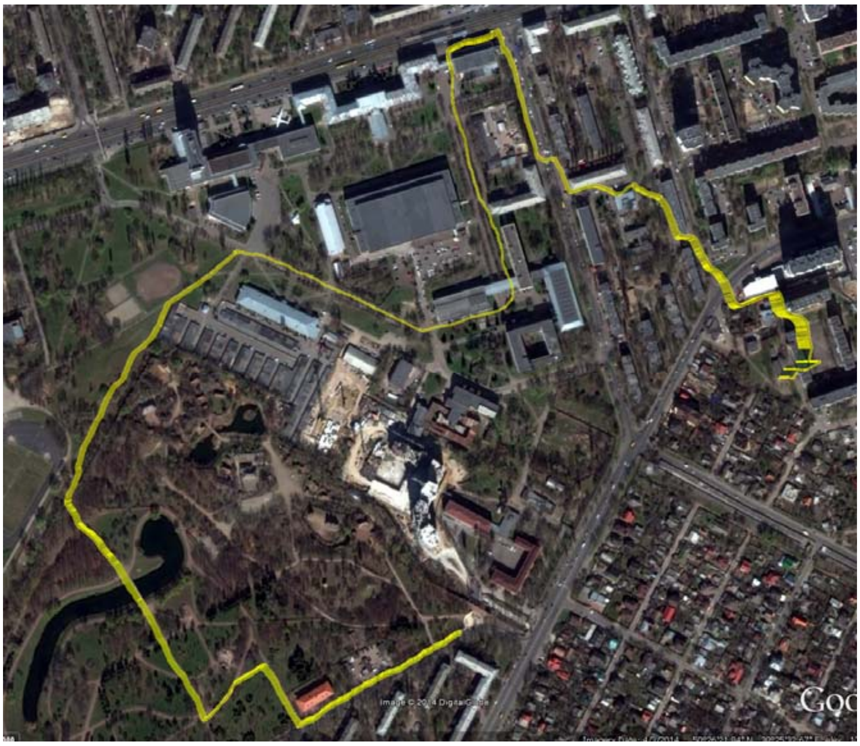

Figure 5.2 – Experimental trajectory by GPS data

5.2. Result of measurement

The results of measurements of sensors are shown in the graphs. (Latitude,longitude,altitude and magnetic field).

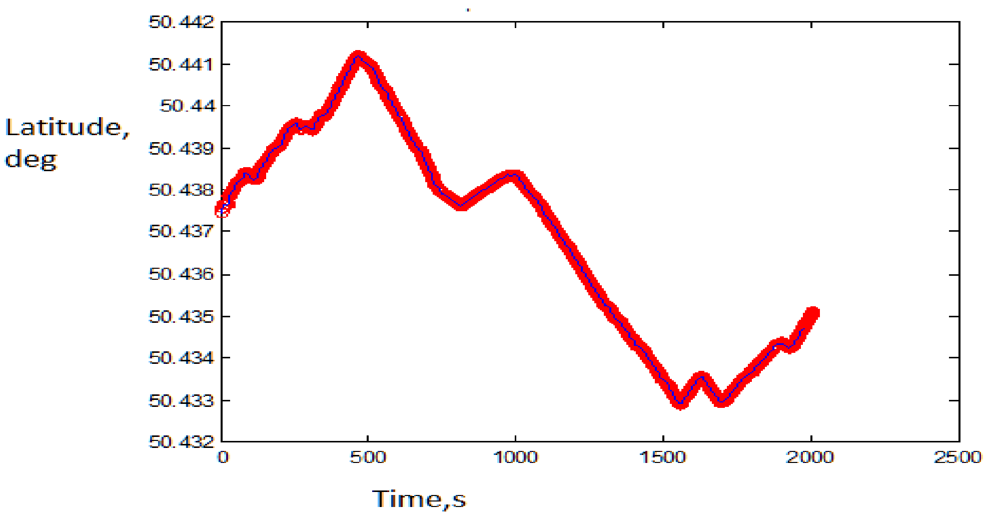

Figure 5.3 – Dependence latitude from time

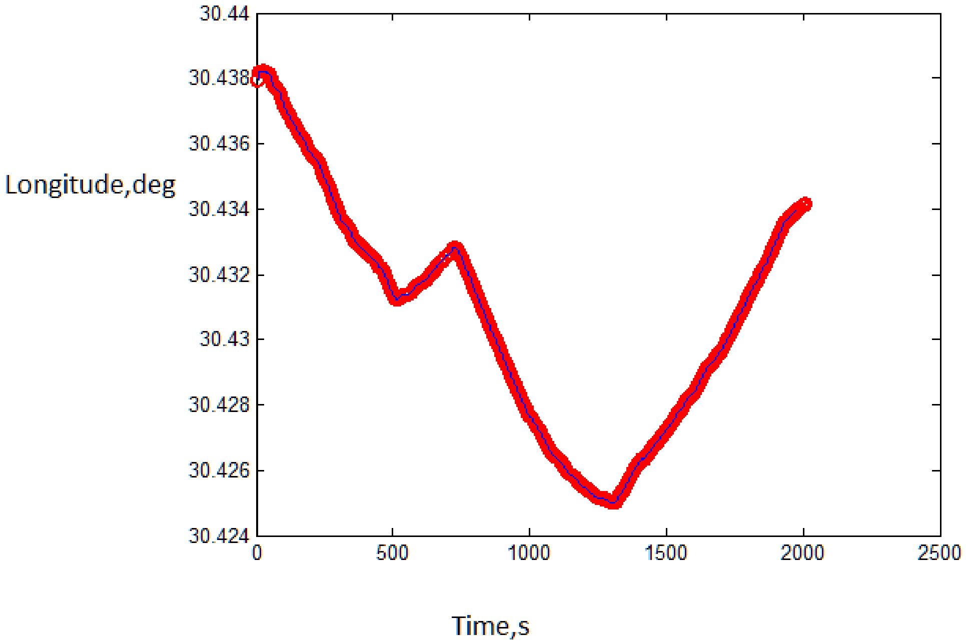

Figure 5.4 – Dependence longitude from time

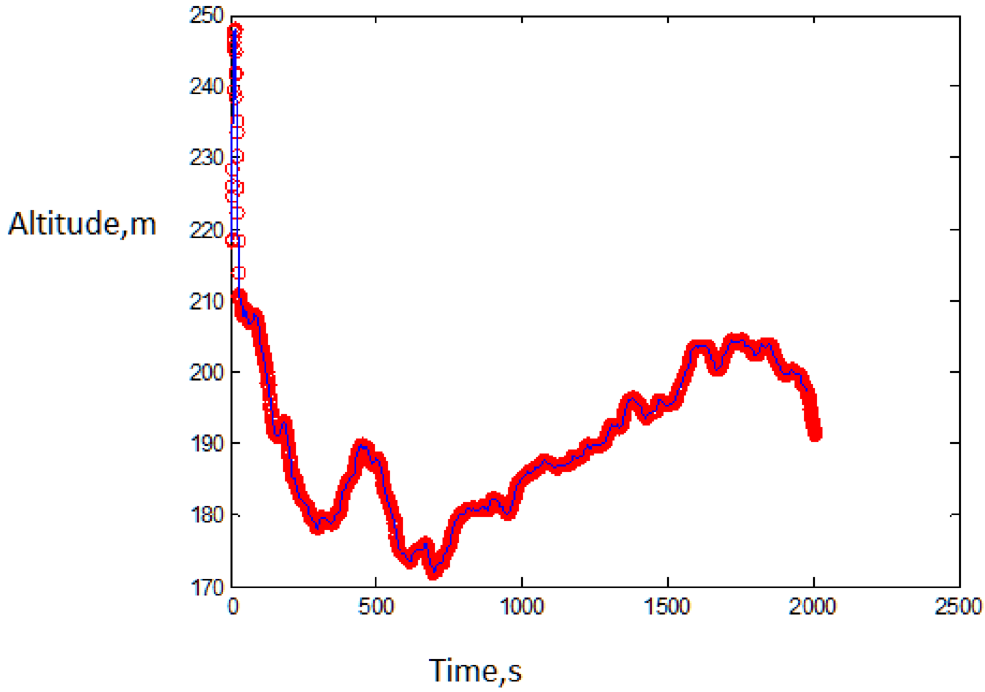

Figure 5.5 – Dependence longitude from time

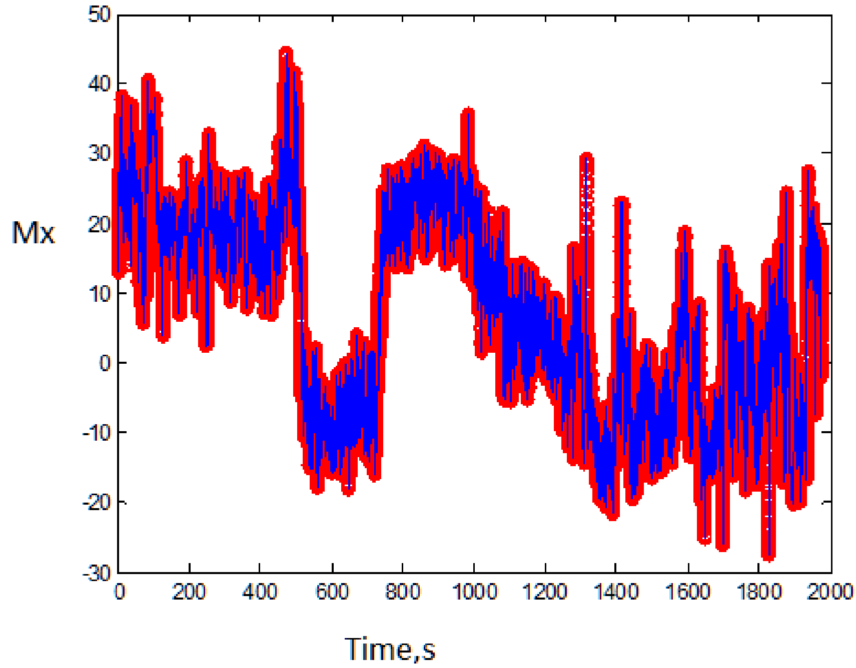

Figure 5.6 – Dependence Mx from time

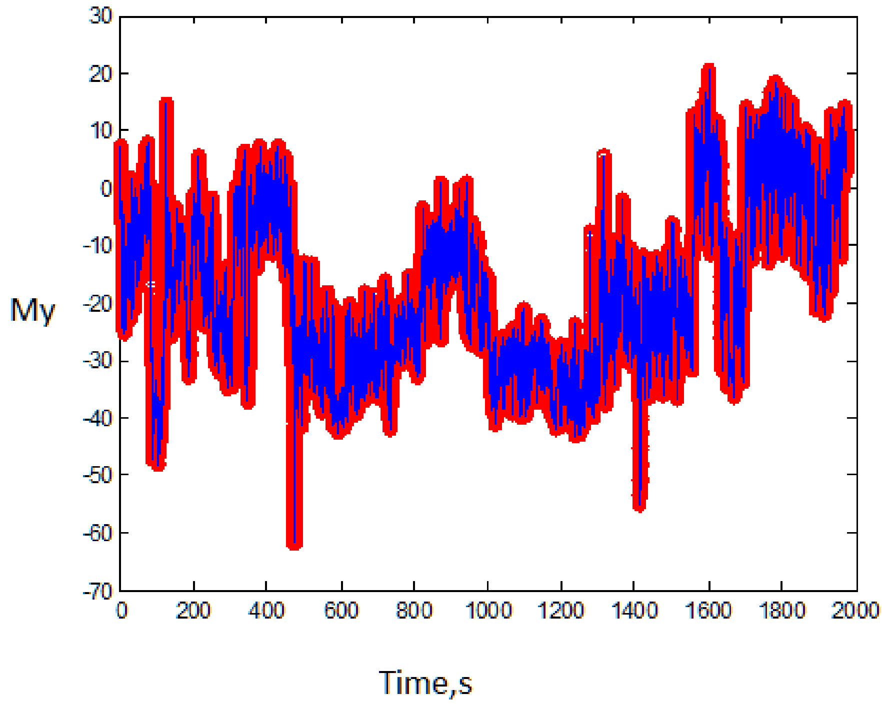

Figure 5.7 – Dependence My from time

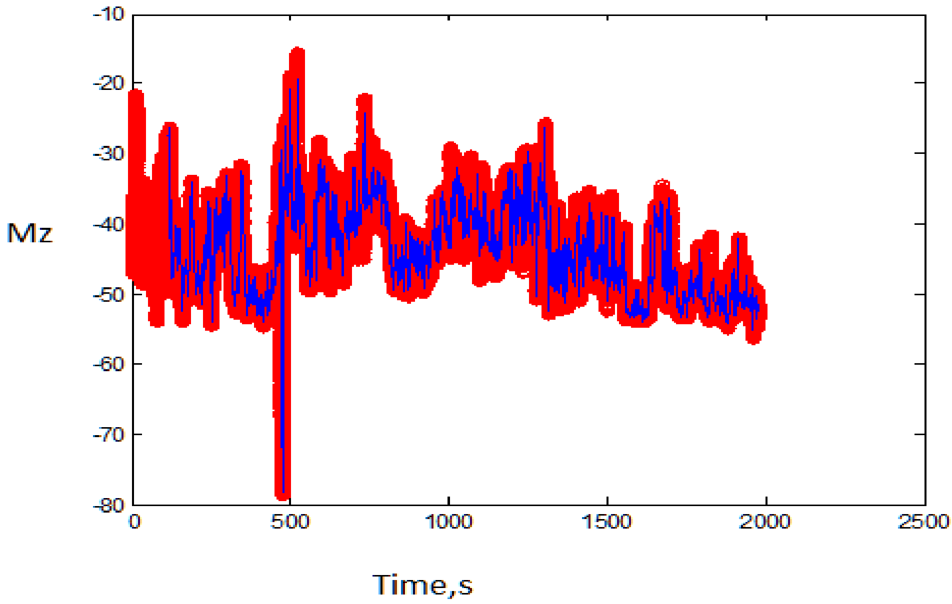

Figure 5.8 – Dependence Mz from time

5.3. Inclination and Declination calculation

At any location, the Earth's magnetic field can be represented by a three-dimensional vector. A typical procedure for measuring its direction is to use a compass to determine the direction of magnetic North. The intensity (T) of the field is proportional to the force it exerts on a magnet. Its angle relative to true North is the declination (D) or variation:

$$D = \arccos\left(\frac{T_{xENU}}{T_{HENU}}\right). \quad (5.1)$$

Facing magnetic North, the angle the field makes with the horizontal is the inclination (I) or dip:

$$I = arctg\left(\frac{T_{zENU}}{T_{HENU}}\right).$$

(5.2)

Horizontal component of intensity vector of magnetic field:

$$T_{HENU} = \sqrt{T_{xENU}^{\;2} + T_{yENU}^{\;2}}\,. \quad (5.3)$$

All of these parameters are important for navigation and other magnetic field applications. That's why let's calculate declination, inclination and intensity for all input data. After that we will have these data across trajectory of mobile phone movement (fig.5.9 – 5.12).

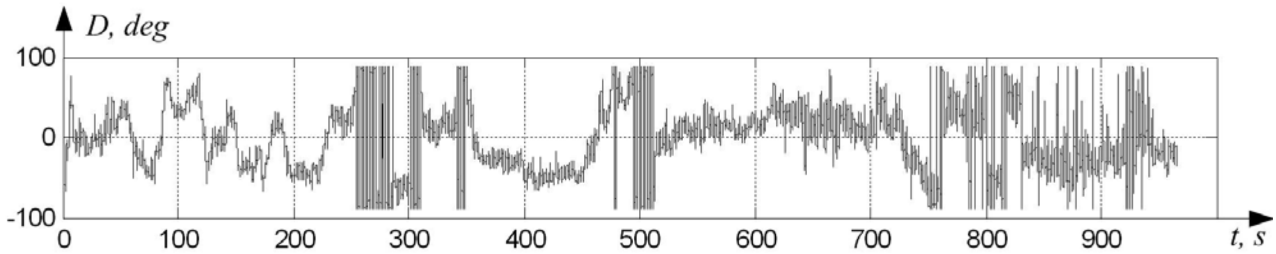

Figure 5.9 – Declination during movement

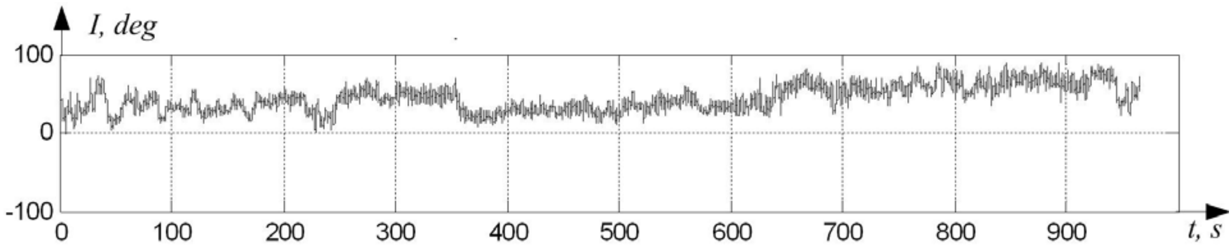

Figure 5.10 – Inclination during movement

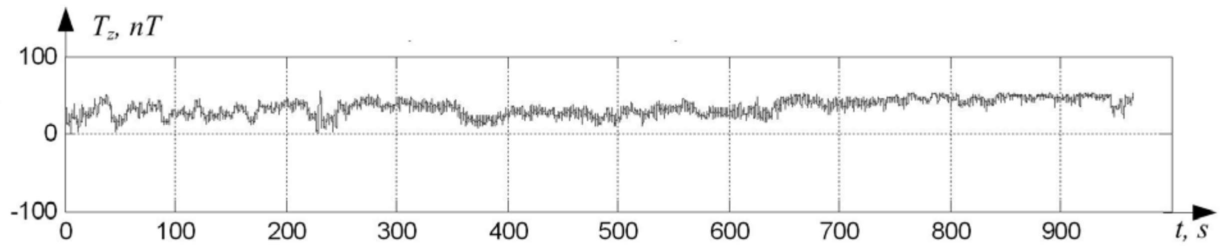

Figure 5.11 – Vertical component of intensity of Magnetic field vector

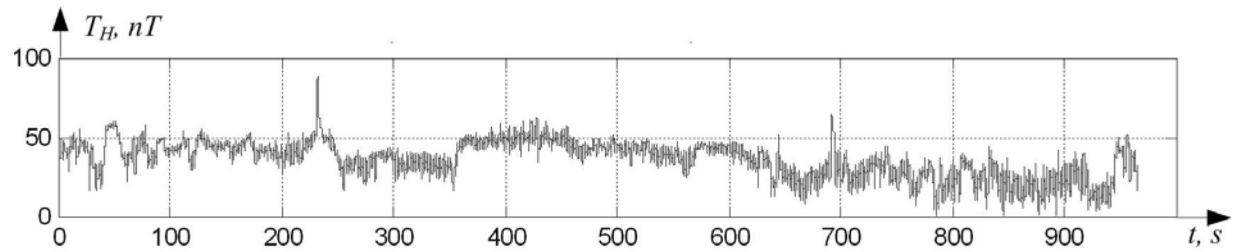

Figure 5.12. – Horizontal component of intensity of Magnetic field vector

5.4. Local magnetic field data processing

The "V4" method has been used to interpolate values of declination, inclination and intensity for area which is close to movement trajectory.

The “V4” method is much like a radial basis function interpolate. These methods are distance based methods, so we will have a single radially symmetric basis function around every data point. The “V4” method will form a linear combination of these basis functions, so it must formulate and solve a linear system of equations, of size the number of data points. It is apparently a Greens' function approach. It uses a full matrix composed of all of the interpoint distances. This will be slow for many points, and extremely memory intensive. In result surface which fit to the data has been calculated (figures from 5.15 to 5.16).

For data verification international world magnetic model has been used. The predicted state of intensity vector of magnetic field for local area of investigation has been calculated by NOAA data with the help of MATLAB specific software on the same date and time of real data measurement. Result of Intensity vector forecast in terms of declination, inclination and intensity are represented on fig.5.17-5.20.

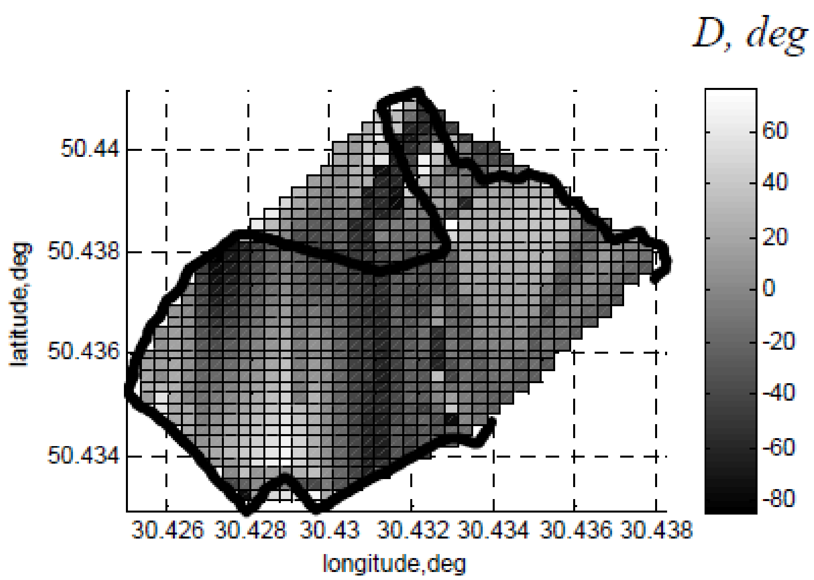

Figure 5.13 – Declination surface interpolation

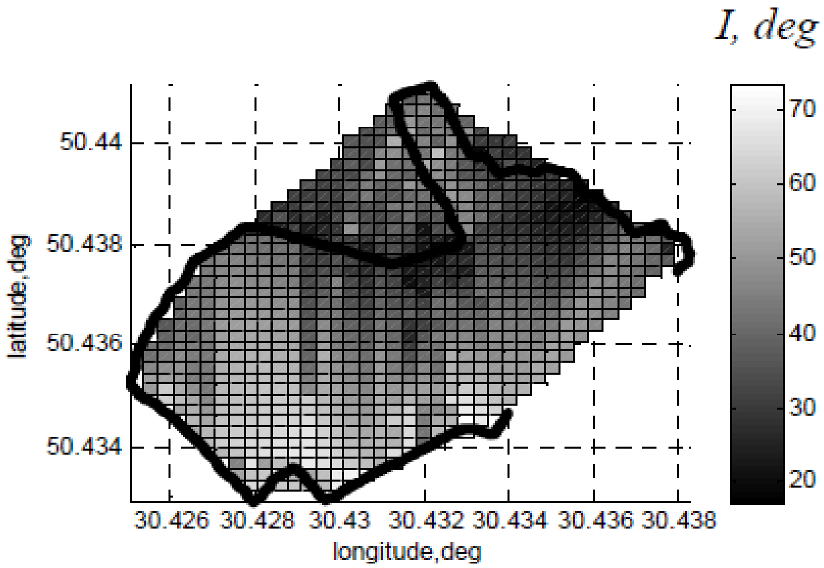

Figure 5.14 – Inclination surface interpolation

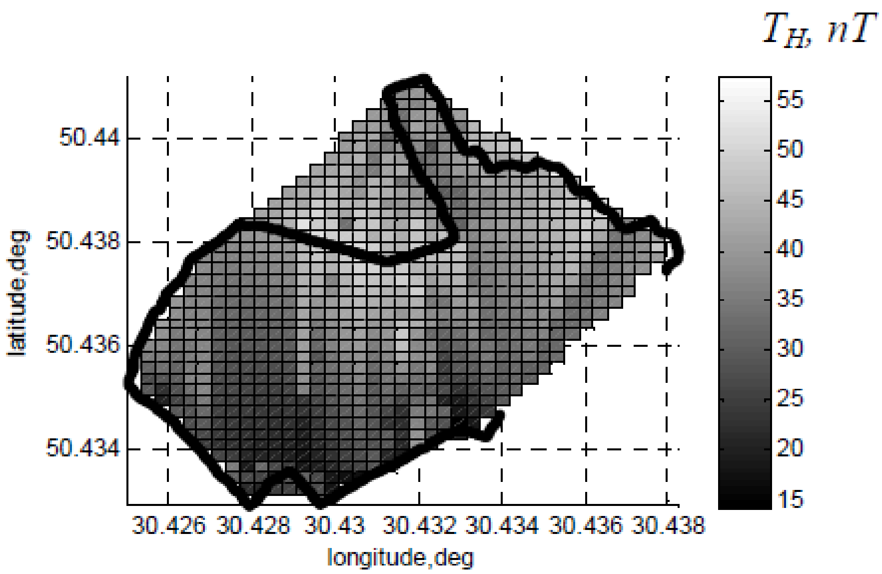

Figure 5.15 – Horizontal component of intensity of
Magnetic field vector surface interpolation

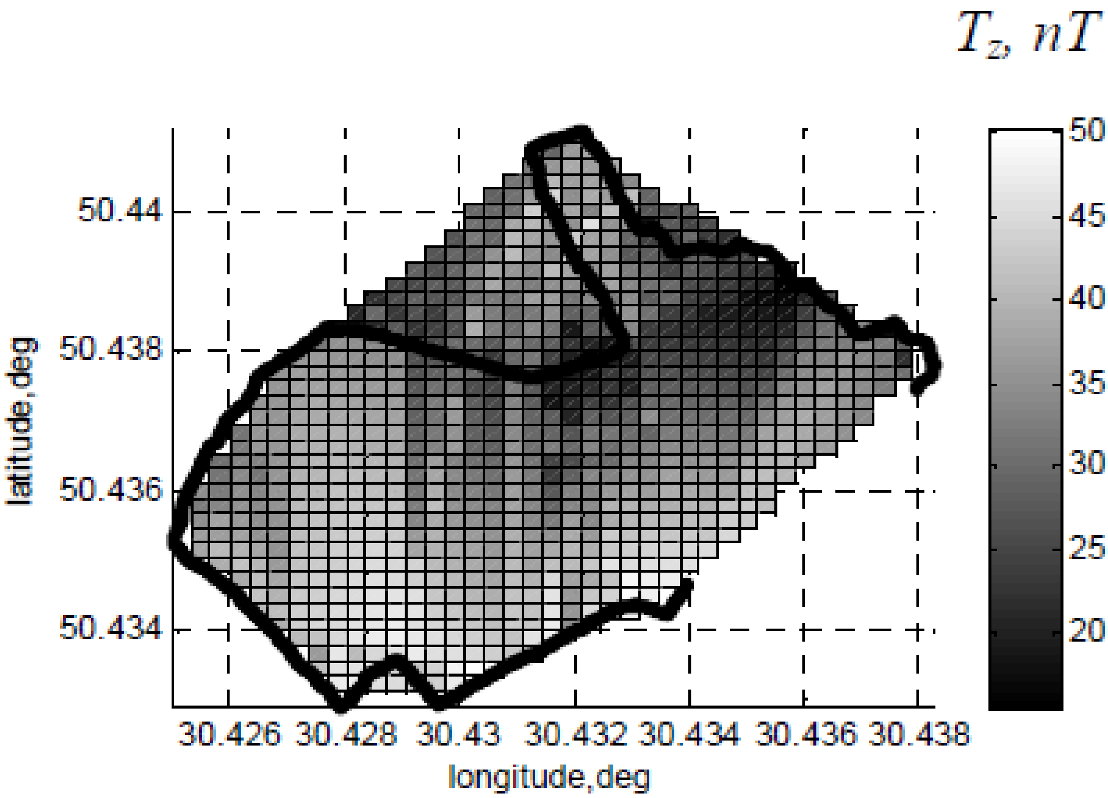

Figure 5.16 – Vertical component of intensity of Magnetic field vector surface interpolation

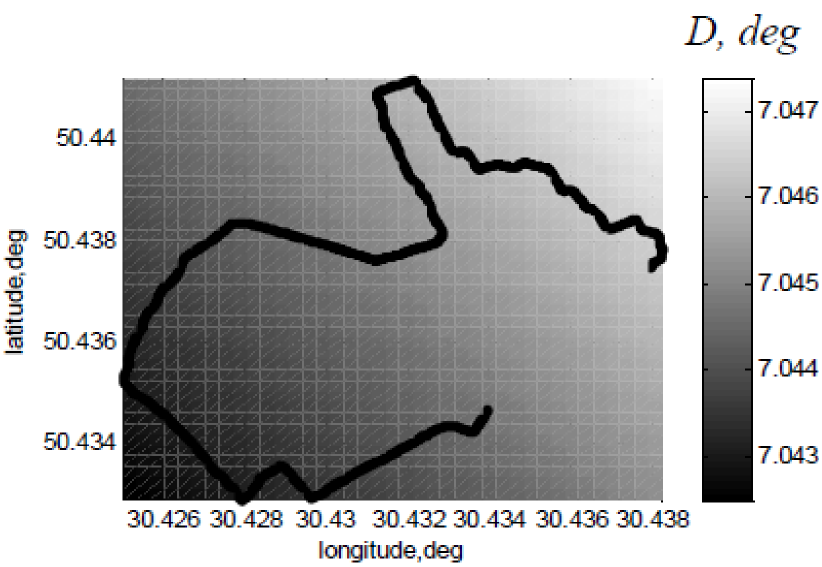

Figure 5.17 – Declination surface interpolation

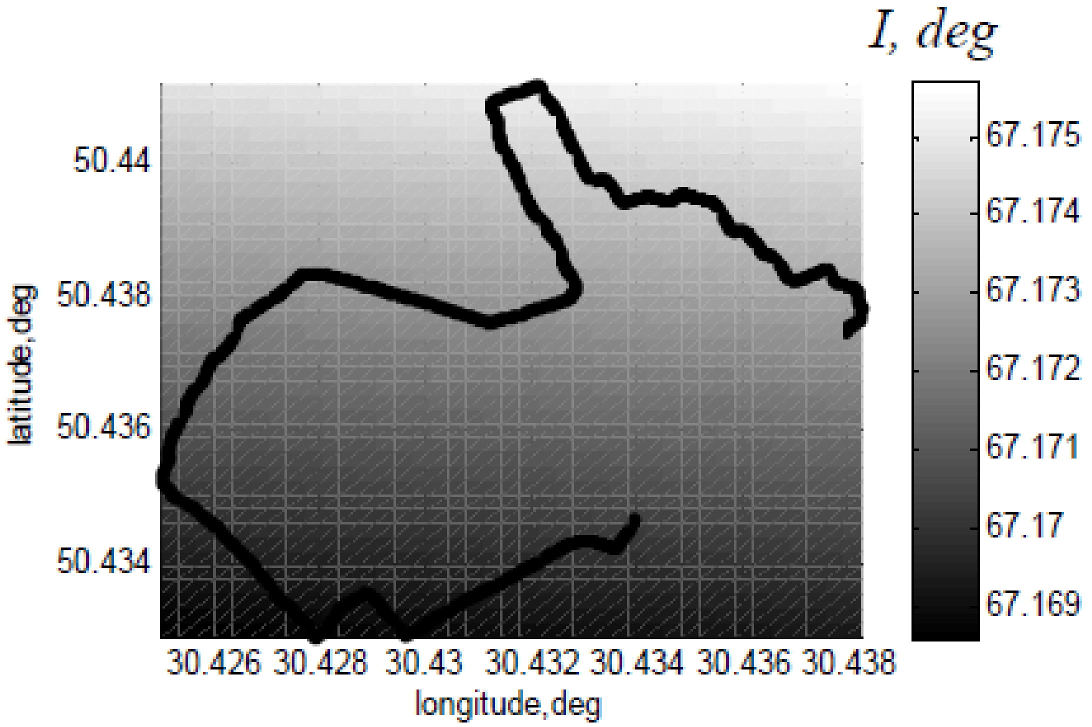

Figure 5.18 – Inclination surface interpolation

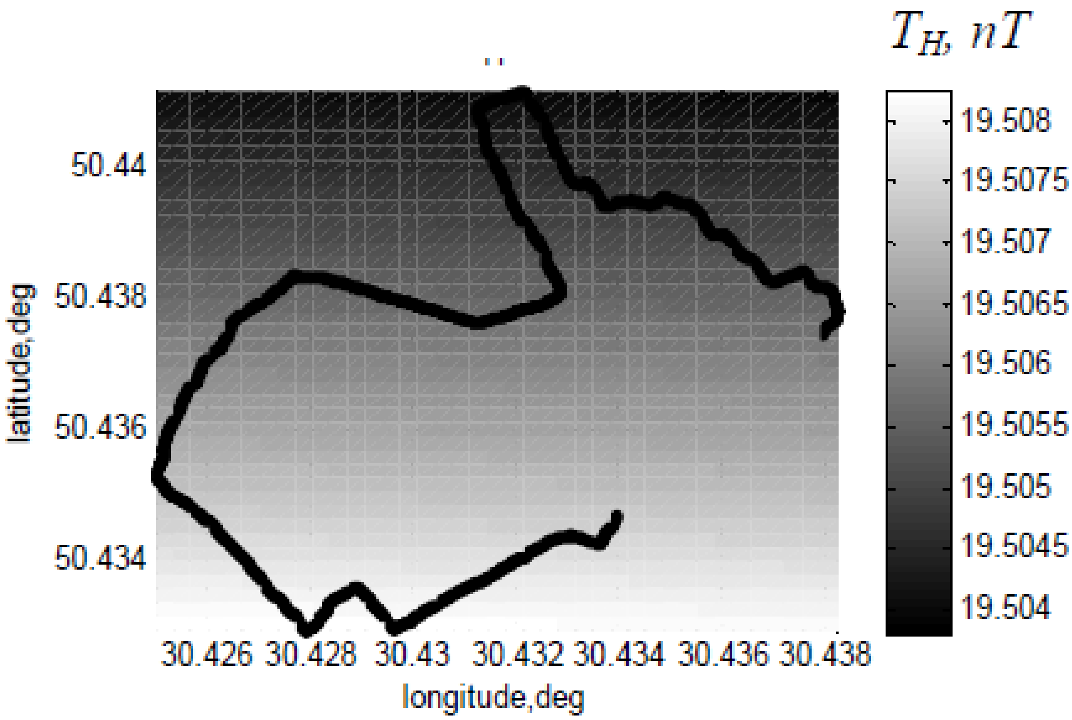

Figure 5.19 – Horizontal component of intensity
of Magnetic field vector surface interpolation

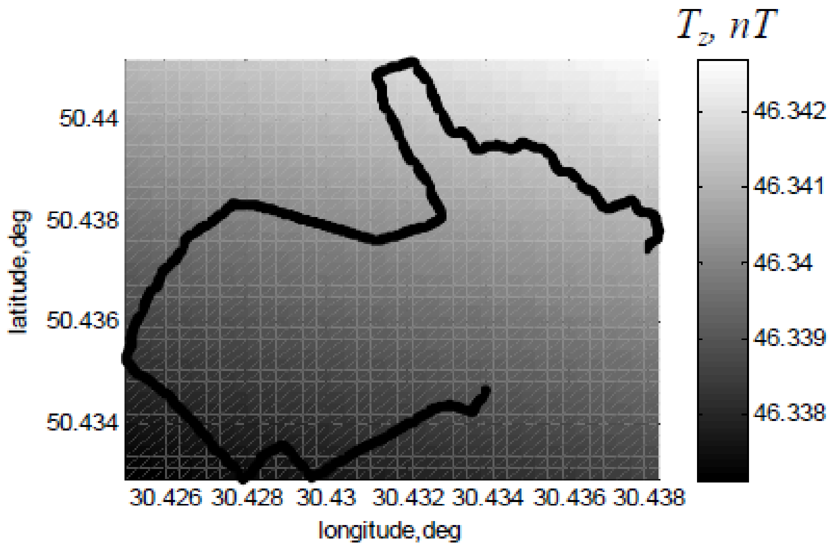

Figure 5.20 – Vertical component of intensity of Magnetic field vector surface interpolation

Conclusions to the chapter 5

This chapter includes results of the experiment. The results represented in figures. All of these parameters are important for navigation and other magnetic field applications. That's why let's calculate declination, inclination and intensity for all input data. After that we will have these data across trajectory of mobile phone movement .

The "V4" method has been used to interpolate values of declination, inclination and intensity for area which is close to movement trajectory.

That's why the aim of this work to describe methodology of local magnetic field parameters measurement by typical users equipment.

CONCLUSIONS

Researches of theoretical bases and the practical organization have allowed making the following conclusions.

Global Earth’s Magnetic field is one of the most important things in planetary structure. Magnetic field is also one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications.

Modern navigation devices and sensors grounded on magnetic field characteristics use magnetic field models which do not contain data about human based part of magnetic field.

During an experiment were used a cell phone Samsung Galaxy I9300 and free Android application "Data Recording" for data collecting and storing.

The main purpose of the work is the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Results of work indicate that mobile phone sensors are possible to use for real time magnetic field characteristics estimation. Parameters of Earth’s magnetic field: declination (fig.5.7), inclination (fig.5.8), intensity, horizontal (fig.5.9) and vertical (fig.5.10) components are extremely important for navigation purposes. Represented methodic of theses parameters evaluation shows the cheapest way to improve navigation equipment functionality. Result of interpolation has been verified with forecasts by international World Magnetic Model.

Represented methodic of theses parameters evaluation shows the cheapest way to improve navigation equipment functionality.

As a result we processed our data and get appropriate graphs and results.

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APPENDIX A
Program code for matlab software

```
clc
clear all
close all
tic
load travel_nau_02.mat;


time_ori=ori(:,1);
azimut=ori(:,2);
pith=ori(:,3);
v=find(pith<0);
pith(v)=360+pith(v);
roll=ori(:,4);
b=find(roll<0);
roll(b)=360+roll(b);

time_m=magnetic_xyz(:,1);
mx=magnetic_xyz(:,2);
my=magnetic_xyz(:,3);
mz=magnetic_xyz(:,4);

time_loc=location(:,1);
lon=location(:,3);
lat=location(:,4);
alt=location(:,5);

%coordinat interpolation for sensors data

start_tim=min(time_loc);
m=find(time_m>start_tim);
start_time=time_m(m(1));
figure('Color','white','Name','coordinats interpolation');
lon_s=interp1(time_loc,lon,time_m(m(1):length(time_m)));
subplot(2,1,1)
plot(time_loc,lon,'or',time_m(m(1):length(time_m)),lon_s,'>g')
legend('GPS data','interpolation')
title('longitude interpolation')
subplot(2,1,2)
lat_s=interp1(time_loc,lat,time_m(m(1):length(time_m)));
plot(time_loc,lat,'or',time_m(m(1):length(time_m)),lat_s,'>g')
legend('GPS data','interpolation')
title('latitude interpolation')

%body to ned transformation
poin=length(lon_s)-100;
for i=1:poin

  C=[sind(azimut(i)).*cosd(pith(i)), cosd(roll(i))*cosd(azimut(i))+sind(roll(i))*sind(azimut(i))*sind(pith(i)),-
sind(roll(i))*cosd(azimut(i))+cosd(roll(i))*sind(azimut(i))*sind(pith(i)); cosd(azimut(i)).*cosd(pith(i)), -
cosd(roll(i))*sind(azimut(i))+sind(roll(i))*cosd(azimut(i))*sind(pith(i)),
sind(roll(i))*cosd(azimut(i))+cosd(roll(i))*cosd(azimut(i))*sind(pith(i)); sind(pith(i)), -sind(roll(i))*cosd(pith(i)), -
cosd(roll(i)).*cosd(pith(i))];
    NED=C*[mx(i);my(i);mz(i)];
    xn(i)=NED(1);
    yn(i)=NED(2);
```

```
  zn(i)=NED(3);
end

d=atand(yn./xn);
h=sqrt(xn.^2+yn.^2);
inc=atand(zn./h);

figure('Color','white','Name','Magnetic field parameters');
subplot(4,1,1);
plot(time_ori(1:poin)',d);
grid on;
xlabel('time,s');
ylabel('declination');
title('dependence of declination form time');

subplot(4,1,2);
plot(time_ori(1:poin)',inc);
grid on;
xlabel('time,s');
ylabel('inclination');
title('dependence of inclination from time');

subplot(4,1,3);
plot(time_ori(1:poin)',zn(1:poin));
grid on;
xlabel('time,s');
ylabel('vertical component');
title('dependence of vertical component form time');

subplot(4,1,4);
plot(time_ori(1:poin)',h);
grid on;
xlabel('time,s');
ylabel('horizontal component');
title('dependence of horizontal component form time');

acur=10;
x=lat_s(1:acur:poin);
y=lon_s(1:acur:poin);
z=d(1:acur:poin)';

[xx, yy] = meshgrid(linspace(min(x),max(x),40), linspace(min(y),max(y),40));
zz = griddata(x,y,z,xx,yy);

zi=inc(1:acur:poin)';
zzi = griddata(x,y,zi,xx,yy);

zh=h(1:acur:poin)';
zzh = griddata(x,y,zh,xx,yy);

zn=zn(1:acur:poin)';
zzn = griddata(x,y,zn,xx,yy);

figure('Color','white','Name','Sensors data');
subplot(2,2,1);
surf(xx,yy,zz);
axis([min(x),max(x) min(y),max(y)])
xlabel('latitude,deg');
ylabel('longitude,deg');
zlabel('declination,deg');
title('DECLINATION');
```

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